VERIFICATION, VALIDATION AND CREDIBILITY ASSESSMENT OF A COMPUTATIONAL MODEL OF THE ADVANCED RESISTIVE EXERCISE DEVICE (ARED)

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INTRODUCTION: The Advanced Resistive Exercise Device (ARED) is the resistive exercise device used by astronauts on the International Space Station (ISS) to mitigate bone loss and muscle atrophy due to extended exposure to microgravity (μg). The Digital Astronaut Project (DAP) has developed a multi-body dynamics model of the ARED using Adams™ (MSC Software, Inc., Santa Ana, CA) that has been integrated with exercise biomechanics models for use in spaceflight exercise physiology research and operations [1-3]. In an effort to advance model maturity and credibility of the ARED model, the DAP performed verification, validation and credibility (VV&C) assessment of the analyses of the model in accordance to NASA-STD-7009 [4] 'Standards for Models and Simulations'.

METHODS: The ARED simulation model was created using CAD geometry provided by the Johnson Space Center (JSC) ARED engineering team. Additional parameters that were not part of the CAD were created such as bearing friction, hard stop interactions, and force due to vacuum. The JSC engineering team also provided performance data from the actual ARED currently on board the ISS. The performance data on the flight version of the ARED was broken into seven categories that focused on specific regions of the ARED device as well as Vibration Isolation System (VIS), which structurally isolates the ARED from the ISS. The seven categories are:

- Load Adjustability of the lifting bar
- Leak Testing on the Vacuum Cylinders
- Lifting Bar Range of Motion
- VIS Range of Motion
- VIS Spring performance
- VIS Damper performance
- VIS Mass Properties

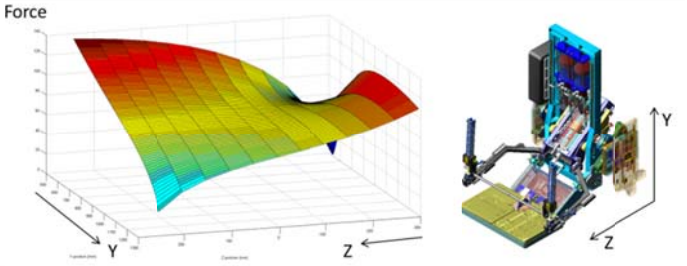

Figure 1: Variation in Force at lifting bar with respect to bar position (left) and ARED Adams™ model (right) for orientation reference.

Each data set was statistically organized to compare against a parameter in the ARED Adams™ model. The comparison also required matching the simulated model to the setup and initial conditions of the actual flight version of the ARED. When values were not within acceptable range, the setup of the model simulation was investigated for modeling error and corrected. Otherwise, additional analysis was performed on the discrepancy to highlight the key parameters in the simulation or the data that contribute to the mismatch. Each data set received a credibility assessment in accordance to NASA-STD-7009 and the entire set was also consolidated for an overall assessment.

RESULTS: The parameters created in the simulation were verified using manufacturer's data for springs, dampers, and bearings. Force in the Vacuum Cylinders was also verified using the ideal gas law equation. The force at the lifting bar proved to show a great dependence on the position of the bar location (Figure 1) which was not defined clearly in the flight data. Further investigation of the simulation showed a theorized region of the bar where the force is relatively less throughout the stroke in the Y direction. Leak Testing on the Vacuum Cylinders led to further analysis between the force calculated in the simulation and the tolerances in the flight model components. The other parameters listed showed great consistency between simulation and flight model. The overall credibility score based on the NASA-STD-7009 process is 2.29 with a threshold set at 3.07.

CONCLUSIONS AND FUTURE WORK: The VV&C results show that the ARED model closely matches performance of the actual flight hardware, however additional work is required to increase the credibility of the model to meet the required threshold of 3.07. Future work will involve using video data from exercise by the astronauts while on-orbit, and using the dynamic motion of the ARED for validation of the simulation. A similar simulation of the ARED is also currently being developed using OpenSim.

REFERENCES: [1] Humphreys et al., Poster #4104, *HRP IWS 2012*, 14-16 Feb. 2012, Houston, TX. [2] Thompson et al., Poster #1085, *IWS 2013*, 12-14 Feb. 2013, Galveston, TX. [3] Newby et al., Poster #1085, *IWS 2013*, 12-14 Feb. 2013 Galveston, TX. [4] NASA-STD-7009: Standard for Models and Simulations, 2008. NASA: Washington, DC.